Model-Free Prediction of Thermal States of Robot Joint Motors Using Deep Learning

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Abstract: In this work, deep neural networks made up of multiple hidden Long Short-Term Memory (LSTM) and Feed Forward layers are trained to predict the thermal behavior of the joint motors of robot manipulators. A model-free approach is adopted. It allows for the accommodation of complexity and uncertainty challenges that might compromise the identification and validation of a usually large number of parameters of an approximation model hardly available. By contrast, sensed joint torques are collected and processed using the machine learning approach to foresee the thermal behavior of joint motors. Prediction results related to the thermal dynamics of joint motors of a redundant robot with seven joints are presented.

Keywords: Robotics, Thermal Management, Artificial Intelligence/Machine Learning.

1. INTRODUCTION

2. BACKGROUND/RELATED WORKS/STATE OF THE ART

2.1 Review Stage

2.2 Equations

Some words might be appropriate describing equation (1), if we had but time and space enough.

$$\frac{\partial F}{\partial t} = D\frac{\partial^2 F}{\partial x^2}. \tag{1}$$

See Able (1956), Able et al. (1954), Keohane (1958) and Powers (1985).

Of course LaTeX manages equations through built-in macros. You may wish to use the `amstex` package for enhanced math capabilities.

2.3 Figures

2.4 Tables

3. DATA ACQUISITION, TEMPERATURE APPROXIMATION AND PREPROCESSING

- Kinova Gen3 7 DoF Robot
- OPC UA Server and Client (data: pos, temp, torques, velocities and current), create Figure
- randomly generated (restrcited) joint angles/trajectories
- (reference to streamlit app?)
- Fit function with collected data - guassian2 function?
- description of data preprocessing for LSTM and FF

The following section describes the data acquisition, the temperature curve approximation and the data preprocessing for the neural networks.

3.1 Data aquisition

The data of a Kinova Gen3 7 degrees of freedom ultra-lightweight robtic arm [kinova], was recorded using a specially developed OPC Unified Architecture server [OPC UA, Girke]. Positions, temperatures, torques, velocities and currents of each of the seven joints are stored, via a client application, as parameters in CSV files and subsequently processed for the neural network trainings, see Fig. 1. To cover a wide range of robotic movement, both randomly generated joint angle trajectories and selected Cartesian trajectories for pick and place tasks, for example, were generated. The trajectories were initially performed at varying speeds and with different payloads. The duration of each movement was also varied in order to analyze the temperature rise and the cooling behaviour of the joints. For cooling, the robot was positioned in a vertical position, as this joint configuration imposes minimal load on the joints. To prevent collisions due to randomly generated joint angles, the random angular values were constrained within minimum and maximum limits. The result of this experiment indicate that joint 2 and joint 4 experience the most temperature increase and cooling. The data is freely available on our web app [pics and/or link to app with footnote? further explanation of the web app?], which automatically visualizes the CSV files and displays the specific joint data. [1] For this reason, the focus was first placed on the 4th joint, while all other joints were fixed at 0°. Only the 4th joint was actuated with randomly generated values between two varying minimum and maximum angle limits (for example -90° and +90°).

[1] https://irolabkinova.streamlit.app

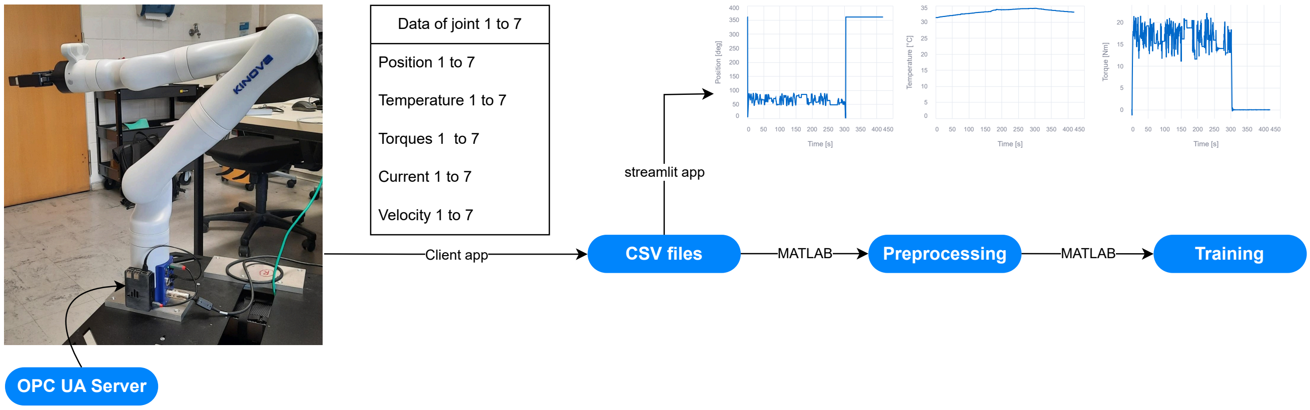

Fig. 1. Kinova data acquisition via OPC UA Server

htbp

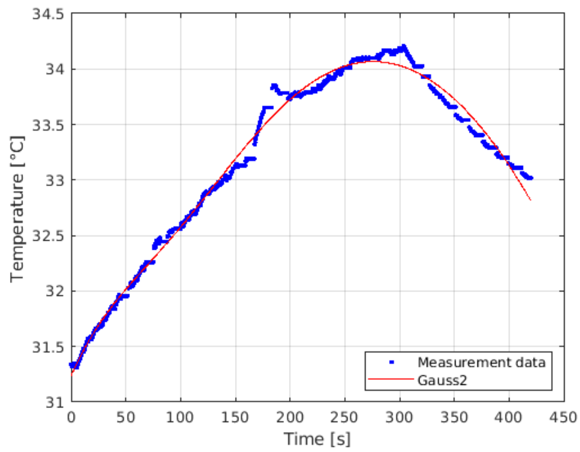

Fig. 2. Approximation of the temperature curve of the 4th joint with the Gauss2 function

3.2 Temperature approximation, ONLY AN EXAMPLE MIGHT NOT INCLUDE?

The temperature curve can be represented approximately with a Gaussian model (Gauss2) as shown in Fig. 2 and (2):

$$f(x) = a_1 \cdot \exp\left(-\left(\frac{x-b_1}{c_1}\right)^2\right) + a_2 \cdot \exp\left(-\left(\frac{x-b_2}{c_2}\right)^2\right) \tag{2}$$

With the coefficients for Fig. 2:

$$a_1 = 34.07, \quad b_1 = 276$$
$$c_1 = 743.2, \quad a_2 = 1.668$$
$$b_2 = -26.71, \quad c_2 = 103$$

4. PROPOSED MODELS (VARIOUS LSTMS, FEEDFORWARD) [AND COMPARISION?]

- various LSTMs (Strcuture: Hyperparameter Learning Rate, Epochs, Batch Size, no. of Layers, Regularization, adam optimization, RMSE, True vs Predicted Temps, etc.)
- FeedForward (same as above)
- fitted function?
- Comparisions

4.1 Figures and Tables

5. DISCUSSION?

?

6. CONCLUSION

A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

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Place acknowledgments here.

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Appendix A. A SUMMARY OF LATIN GRAMMAR

Appendix B. SOME LATIN VOCABULARY